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ABSTRACT

Focusing on the need for energy to sustain economic development on a long-term basis, the document examines energy options of the post-petroleum era in developing nations. Nuclear power and solar power are the most important among proposed alternative energy sources. Limited applicability of nuclear technology to the Third World is discussed. Problems include the need of most developing nations to seek foreign fuel to power nuclear plants, the difficulty of designing nuclear facilities that work equally well in different environments, and the problem of decommissioning radioactive facilities at the end of their usefulness. Energy-related research and experiments indicate that the most likely sources for new energy are solar (sunlight, wind, hydropower, and biomass). Factors which should encourage the Third World to harness solar energy sources include: a general abundance of sunlight, a dispersed and predominately rural population (which encourages decentralized energy resources), prohibitive cost of conventional energy, customary dependence on indirect solar sources such as firewood, and insignificant capital investment in petroleum-powered energy. Various objections and reservations concerned with the transition to solar energy are evaluated. The conclusion is that solar energy, the most viable energy source in the post-petroleum age, can contribute positively to economic development in both developing and industrialized nations. (Author/DB)

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Energy for Development: Third World Options

Denis Hayes

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The Third World may enter the solar era before the industrial world does. Several features common to developing countries make such a prospect seem likely. Developing nations, by and large, tend to be more richly endowed than their industrial counterparts with sunlight. Their populations tend to be dispersed enough to facilitate the exploitation of decentralized energy resources: about half the people in Latin America, 70 percent in South Asia, and 85 percent in Africa still live in rural areas. In the Third World, the current high cost of conventional energy, especially electricity, has already made solar options economically competitive. Far from being exotic prototypes fit for development in the year 2000, many solar devices have already proven themselves simple and practical. Finally, since the Third World already obtains much of its energy from indirect solar sources (mostly firewood), the initial steps toward a solar economy involve no more than an increase in the efficiency of usage.[1]

A Third World decision to take a leadership role in harnessing sustainable energy sources would be wise. Although the world is not running out of energy, it *is* running out of oil. The oil-consuming countries of the world have been living on capital, not income. World oil production is expected to turn downward within 10 to 18 years, and severe regional shortages are likely to develop well before then.[2] Eighty percent of the world's oil supply will have been consumed during the lifetime of the current generation. Consequently, it is critically important and morally obligatory for all countries, rich and poor, to invest a large fraction of the remaining oil in building an energy system that can be sustained in the post-petroleum era.

The industrial world is designed to run on oil. Massive road building programs dwarf all other public works; automobile production has become central to the economic well-being of whole nations. If the

developing countries invest vast sums of scarce capital copying today's industrial powers, the petroleum era will have passed before their investments bear fruit. If, instead, developing countries foresightfully assess the human prospect and make their investments accordingly, they may be spared making major commitments to the petroleum era in its dying phase.

Rather than using tax breaks as incentives to encourage foreign interests to set up automobile plants on their soil, Third World countries might, for example, accept only those factories that produce vehicles that run on fuels other than oil. Rather than devote large portions of their budgets to investments in highways, they might better invest in communication systems and railroads. Rather than laying out huge new cities to accommodate migrants fleeing the countryside, they might do well to spend the same money making rural villages more livable.

Tomorrow, both the industrial world and the agrarian world are likely to be turning to solar resources—sunlight, wind, hydropower, and biomass—for their commercial energy. The Third World, however, has an advantage in that it can take a shortcut past the fossil fuel cul-de-sac. While the industrial world has 90 percent of its capital stock invested in buildings and equipment that are ill-suited to a solar transition, the Third World can undergo rapid economic growth with a clearer vision of its ultimate goal.

Until recently, the strongest impediment to the development of solar power in the Third World has probably been the industrial world's pursuit of a different course. Most Third World policymakers looked to the advanced industrial states as models and they found no solar-powered societies to emulate. Moreover, because the research and development capacities of the Third World have been limited and the industrial research community has neglected solar energy, little innovative work has been done. Even today, much of the Third World appears reluctant to play a leadership role in developing energy technologies. An internationally recognized ethanol-from-biomass program in Brazil is hampered by domestic skepticism—by critics who wonder

"The Third World can take a shortcut past the fossil fuel cul-de-sac."

why the United States isn't developing ethanol if it's so great. Fortunately, such skepticism is less pervasive now than in years past.

Development theory has undergone profound changes in the last decade, and few Third World countries still seek to imitate the United States or the Soviet Union. It is now commonly recognized that development can be approached on many roads—that more than one path leads from "underdeveloped" to "developing" to "developed." The most successful Third World leaders have been those, such as Mao, Ghandi, and Nyerere, able to map out a unique development strategy based upon their nations' indigenous cultures and resources. That the West does not use biogas as an energy source has not, for example, deterred China from building an estimated 4.3 million biogas plants in the last three years.

As the end of the petroleum era approaches, all nations—rich and poor—face some hard choices. Energy, "the capacity to do work," obviously influences economic well-being.[3] Moreover, the kind of new energy sources developed may ultimately be of more importance to human well-being than the quantity of energy those sources make available. To a greater extent than most people realize, history has been shaped by humankind's choice of energy technologies. The use of draft animals, sailing ships, and waterwheels presented new opportunities to our ancestors, and for a time each technology became crucial to the "quality of life." The introduction of the coal-fired steam engine was a precondition of the industrial revolution. Fired by oil-based fuels, internal combustion engines and turbines shaped the transportation systems of the modern industrial world, which in turn determined settlement patterns. The energy technologies we choose today will have far-reaching effects tomorrow.

The earth has never faced, and does not today face, a shortage of energy. Every day the sun delivers thousands of times more energy than humankind employs from all conventional sources. The trick is to harness that energy to do work at a price people can afford. Winds, rivers, coal, and oil were available long before people began to use them. Many watersheds in human history have occurred when tech-

nologies capable of turning previously untapped energy to good purpose were introduced. Today, solar energy displays just such a technological opportunity.

Solar technologies hold many attractions for developing countries. A particularly important social advantage is their potential for promoting development in previously ignored rural areas where it is most needed. Without strong rural development programs based on decentralized energy sources, urban migration will become torrential, exacerbating the already dire urban problems brought into focus at the United Nations Conference on Human Settlements in 1976.[4]

Many solar technologies will make economic sense for the Third World before they do for the industrial world. Electricity produced from solar energy is a good case in point. In rural areas of poor countries where no transmission and distribution infrastructure exists, power from centralized plants is not available. The World Bank estimates that rural electrification programs had "reached" about 12 percent of the people in the rural Third World by 1971. Only half of these people—a mere 6 percent of rural residents—could afford to buy power.[5]

In August 1977, a team from the United States National Academy of Sciences conducted a joint workshop on solar power with the Tanzanian National Scientific Research Council. At this workshop, the cost of electricity for Tanzanian villages from diesel generators and from the national power grid was compared with the cost of power from five decentralized, renewable sources: wind power, small-scale hydropower, biogas, solar refrigeration, and photovoltaics. Comparative costs were found to depend heavily upon how much energy was needed, how remote the village needing the energy was, and under what financial terms the equipment was purchased. For some purposes, each of the five renewable technologies had an economic advantage over both the national grid and diesel generation. Three of the five were economically competitive under all circumstances; for uses in which the biogas could be burned directly rather than converted first into electricity, four out of five were competitive. Even the

least competitive technology—photovoltaics—will hold an economic advantage over conventional sources of electricity by the early 1980s, if the costs drop in accordance with most recent forecasts.[6]

For some specialized applications in isolated areas needing relatively small amounts of electricity, photovoltaics already look economically sound. In 1975, Charles Weiss and Simon Pak of the World Bank studied the cost of using diesel generators, primary batteries, and photovoltaic cells to provide electricity for educational television in some of the Ivory Coast's villages. At the time of the study, photovoltaics already had an economic edge. Since then, the cost of photovoltaic arrays has fallen by almost one-half. Douglas Smith of the Massachusetts Institute of Technology has determined that, at today's prices, solar cells would be an economically competitive power source for shallow irrigation pumps in Chad.[7]

The conclusions of the studies in Tanzania, the Ivory Coast, and Chad are based upon the assumption that the renewable technologies will be financed with conventional loans. If, instead, they are financed over long periods of time at low rates of interest, with so-called "soft" loans, the economic advantages of the renewable energy sources are even more striking.[8]

One of the major functions served by development must be the creation of new jobs. At present, energy is often substituted for labor. At current U.S. prices, 2.5¢ worth of gasoline can perform as much work as a healthy adult laboring from dawn to dusk. One liter of gasoline burned in a one-horsepower engine will provide as much work as a human being can produce in seven days of hard physical labor. Gasoline-derived power is not only cheaper, but also faster and more reliable than muscle power. Hence, the point is sometimes made that major increases in Third World energy use may contribute to mounting unemployment.

It needn't. The alternative is to view full employment as a central goal of development, rather than as just one of the variables considered in the pursuit of some other, more important goal (like a growing GNP).

10 If full employment is pursued intelligently, energy growth can increase, rather than restrict, total employment.

For example, in most developing countries agriculture is by far the largest source of employment, sometimes accounting for 70 to 80 percent of all jobs. But agricultural labor requirements tend to peak sharply during plowing, planting, and harvesting. During the remainder of the year, most laborers are idle. Hence, annual labor productivity and wages are low. As Arjun Makhijani and Alan Poole have suggested, the careful mechanization of plowing, planting, and harvesting could reduce the duration of these bottlenecks sufficiently to allow multiple cropping. Demand for labor would be evened out, agricultural production would be greatly increased, and jobs could be created to handle this increased production, as well as the fertilizer and irrigation it would require. Without an increase in the available energy at times of peak demand for work, multiple cropping would not be possible.[9]

In an era when the gulf dividing rich and poor appears to be widening, technologies for harnessing renewable sources of energy could smooth out some differences. In developing gentle, sustainable energy sources, the Third World and the industrial world can be of mutual assistance, even as each independently pursues its own self-interest. Because most assistance efforts that have depended on altruism have had lackluster records, opportunities for nations to help one another while pursuing separate interests should be especially welcome.

Widespread use of solar equipment in the Third World, where it is already cost-effective, would have positive effects in the industrial nations. The principal handicap faced by many producers of solar equipment is the lack of a market large enough to justify investments in mechanized mass production. With the rapid reductions in cost that assembly lines could bring, decentralized solar devices would find ever more applications in rich lands and poor alike. Such a state of economic affairs is so manifestly in the interest of the industrial world that it warrants granting Third World customers subsidies on

early orders. France, aware of this fact and eager to attract large orders, is now marketing a subsidized solar irrigation pump throughout the Third World.

The international research and development community has finally begun to apply its genius to the problems and potentials of solar energy use. Annual expenditures on solar energy research by the U.S. Government have shot up from about $5 million to more than $300 million in five years, and almost all other industrial lands have boosted their solar programs as well. Moreover, Third World research and development in this area have been improving steadily, and excellent programs now exist in Brazil, Mexico, India, and other countries. The United Nations Environment Program is also promoting the use of renewable energy resources in poor countries by funding model villages that employ several different sustainable energy sources.[10]

All this is not to imply that the Third World's transition to solar technologies will be trouble-free. Many attempts have been made in the last half century to introduce solar technologies in the Third World: typically, the technology has worked, and the technology transfer has not. At times, the technology has been perceived as irrelevant, if not antithetical, to people's real needs (as in the case of solar powered pumps that replaced water carriers for whom no alternative employment existed). In other cases, maintenance personnel have been inadequately trained or crucial replacement parts have not been provided. Sometimes the recipients of the technology have simply not liked the solar gadgets or have not cared to adjust their daily activities to take advantage of the availability of sunlight. And in still other cases, the technologies have been used and have worked perfectly, but their use has concentrated additional wealth in the hands of the elite or otherwise led to undesirable social consequences.[11]

A successful solar transition will require detailed knowledge about energy availability and needs in the Third World—information that does not now exist. Comprehensive studies are needed to determine how much energy of each kind is used for what purposes, and how any additional energy would be spent. And the availability of renew-

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able energy resources at various sites must be surveyed; wind speeds, levels of sunlight, and biological productivity all must be gauged. Local residents must be provided with information about each of the energy options open to them so that they may determine which best suit their needs and aspirations. Finally, political will and technical competence must be mustered to build or acquire the necessary equipment and to keep it running.

The challenge of a solar transition is formidable. But the rewards of success make it a goal worth pursuing. Ultimately, only a solar civilization is sustainable.

Current Supplies

The energy crisis plaguing the Third World dwarfs the industrial world's energy problems. Traditional energy sources—principally firewood, charcoal, and forage for draft animals—are growing scarce and expensive. Where ecological carrying capacities have been exceeded, forests are receding and grasslands are becoming deserts. Traditional fuels and petroleum fuels have both grown so expensive that few poor countries have been able to adjust comfortably to the increases.[12]

Trees, of course, are a renewable energy resource, but they can grow only so fast. When population growth outstrips tree growth, progressive forest deterioration ensues. Each year, the harvested crop grows younger, even though harvesting immature trees diminishes the ultimate energy yield of the land. When people are cold and hungry, there is no humane way to protect juvenile trees.

Twenty-nine percent of the earth's land area was forested in 1963, when the last global forest survey was completed.[13] Subsequent regional surveys have been of uneven quality, but all signs are that Third World deforestation is advancing rapidly. Half of the wood cut in the world, and the overwhelming preponderance of wood cut in the Third World, is used for fuel. In all but a handful of countries, the

resource is being harvested more rapidly than it is being propagated.[14]

A crucial consequence of deforestation is the erosion of topsoil. Erosion can greatly retard the rate at which reforestation projects take root. With every passing year that the land remains denuded, the problem intensifies. Moreover, all lost topsoil has to go somewhere—and all too often that "somewhere" is a reservoir that is vital to the local or even national economy. Engineers who have not anticipated the rate of upstream deforestation have often been unpleasantly surprised to see reservoirs they designed fill with silt in a fraction of the time they had expected. So, erosion can lead to a double energy loss: the tree-growing potential of the land is diminished, while the energy-storage capacity of the downstream dam suffers commensurately. In addition, even as it causes losses in energy supplies, deforestation can result in increased energy *demand*. When land loses ground cover, its capacity to retain rain declines, and the water table beneath such land can fall dramatically. Wells must then be sunk lower, and water pumped a longer distance to the surface.[15]

Few countries have conducted successful reforestation programs, even though this is probably their most potentially lucrative energy-production investment. Reforestation is labor-intensive, requires little capital, and produces a high net-energy yield (especially with fast-growing species, such as eucalyptus). If coupled with ambitious programs to provide every rural villager with a more efficient wood stove, reforestation efforts could reverse the dreadful spiral of environmental deterioration.

Firewood is not the only source of Third World energy in short supply. Oil use had been expanding rapidly in the Third World until the 1973-74 embargo. Then, many developing countries discovered that reliance on imported oil creates vulnerabilities. By one estimate, a shortage of fuel for irrigation pumps in 1974 reduced the wheat harvest in India by a million tons.

The dramatic recent increases in the cost of oil on the world market have had disproportionate effects on the Third World. To be sure,

the cost of oil has increased by the same amount everywhere, but the industrial nations have been in a better position to offset the adverse economic impacts of these price increases.

At the same time that the Third World has been forced to adjust to escalating oil prices, it has also had to pay higher prices for the manufactured goods it imports from the industrial world—prices that reflect not just the higher costs of the oil needed to manufacture these products, but also the higher wages and profits that mitigate the effects of oil-induced inflation in the industrial countries. Third World exports, on the other hand, are generally sold in buyer's markets, so the prices for these products have often failed to rise as fast as the prices of imports. According to figures compiled by the Overseas Development Council, about 50 developing countries have recently seen their "terms of trade"—the relative value of exports versus imports—deteriorate. Moreover, few developing countries have attracted OPEC investment capital, although many industrial nations have. Consequently, many Third World countries have been increasing their debt at a rate that often outpaces their rate of real economic growth.[16]

The bane of Third World importers, oil is a boon to Third World producers. Many geologists believe that new petroleum deposits remain to be discovered within the boundaries or off the shores of poor countries that are not now oil producers. Some authorities believe that these areas may contain half the world's remaining undiscovered oil. Such estimates are necessarily speculative, and much more intensive exploration is clearly warranted. But even the discovery of relatively cheap oil is no cause to postpone developing sustainable energy resources.

World oil prices today are in the range of $13.00 per barrel, even for oil that costs only 50¢ a barrel to extract. Third World nations that discover oil today must—in the course of designing their domestic energy strategies—consider not just the production cost of oil, but also its world market value. Rather than burning this oil to fuel their economies while oil remains "cheaper" than solar technologies, they might be wiser to sell much of their

"Even the discovery of relatively cheap oil is no cause to postpone developing sustainable energy resources."

oil at high prices to countries that have acquired a nearly paralyzing dependence on it. (China, which contains about 20 percent of the world's population and produces less than 3 percent of the world's oil, manages nonetheless to export about 30 million barrels net per annum.) The new Third World oil producers would then be free to invest the revenues in renewable energy technologies that, compared with those built to use oil at international prices, make sense for them. What's more, such developments would allow many African, Asian, and Latin American nations to begin building an energy base that will last as long as the sun.[17]

A handful of Third World countries have coal reserves, and coal will doubtless be tapped as a transitional energy source by some. But coal is distributed even less equitably than oil; few developing countries have coal deposits. Latin America and Africa combined possess less than 1 percent of the world's coal. In contrast, the Soviet Union has 56 percent of the world's coal supply, while the United States contains 19 percent, and Europe has about 6 percent.[18]

In the industrial world, commercial interests with large coal holdings are exerting considerable pressure on their governments to commit public resources to coal development. At the same time, environmentalists and public health agencies are demanding that sulfur, heavy metals, carcinogenic hydrocarbons, and other harmful airborne pollutants emitted during coal combustion be controlled. Some parts of the industrial world now appear likely to commit large fractions of their discretionary capital to coal-conversion technologies, and in the process to refashion much of the physical stock of their economies to accommodate the characteristics of coal as an energy source. They will become increasingly electrified and centralized, and the eventual solar transition will be just that much more difficult to achieve.

Yet, coal is a temporary savior at best. It is ruinous to the land to mine, difficult to transport, bulky to store, and dirty to handle and burn. Emissions of carbon dioxide—an unavoidable consequence of coal combustion—produce a "greenhouse effect," warming the

earth's atmosphere. The consequences, which are cumulative and long-lasting, will likely bring a halt to coal combustion long before the world's supply of coal has been consumed.[19] They will force societies that have geared themselves for a coal-based economy to enter another painful period of adjustment, another "energy crisis," as they redesign their physical way of life to rely upon renewable energy sources. Thus, ironically, the Third World's lack of coal may work to its advantage. While resource scarcities of any sort are not to be envied, developing countries with little or no coal potential may at least be spared costly investments in technologies built to exploit a fuel that can play a transitional role at best.

By making judicious decisions today, the countries of the Third World can avoid the detour through a new coal age and proceed directly into the solar era. They can create the kinds of decentralized societies that must become the worldwide norm if civilization is to be sustained in a humane fashion.

The Nuclear Trap

Some analysts expect nuclear power to play a major role in the Third World. The International Atomic Energy Agency (I.A.E.A.), for example, forecasts that at least 293,000 megawatts, and possibly as much as 437,000 megawatts, of nuclear capacity will exist in the developing world by the year 2000. Such estimates are greeted with fervent enthusiasm by the companies that manufacture nuclear reactors and fuels. Having watched their markets in the industrial world disappear in recent years, with deferrals and cancellations greatly outnumbering new reactor orders and with many industrial countries cutting their official forecasts for nuclear growth by two-thirds, the nuclear industry has eagerly turned to Third World markets to hawk its wares.[20]

But the I.A.E.A.'s rosy forecast and the enthusiasm of nuclear vendors notwithstanding, the entire Third World now has only 2,000 megawatts of installed nuclear capacity. For many reasons, the

I.A.E.A.'s prediction of a 200-fold increase in nuclear capacity over the next two decades seems out of line. A central reason is that nuclear power, like oil, would be an energy "import" for most countries and an expensive one at that. The largest costs associated with the development of nuclear power are for capital equipment and for fuel, and almost all this money would be spent in the industrial world. In many developing countries, the cost of a single small nuclear reactor exceeds the value of all annual exports. Naturally, the purchase of such a reactor would pose extraordinary balance-of-payments problems.

The adoption of nuclear power would also strengthen rather than diminish the technological dependence of poor countries upon rich ones. Since few developing countries are likely to develop a domestic nuclear manufacturing capacity within the foreseeable future, most would be forced to rely upon the goodwill of the nuclear vendors when parts wear out or suffer damage and new equipment is needed.

Most Third World countries would also have to turn abroad for fuel, because uranium is no more evenly distributed than oil or coal. Just four nations—the United States, Canada, Australia, and South Africa—possess 85 percent of the entire non-communist uranium base. Australia has stopped exporting uranium, while Canada and the United States have limited their uranium exports for political reasons.[21]

Even if uranium were less scarce and costly, its use would still entail reliance upon the industrial world. Uranium ore cannot simply be shoveled into a power plant like coal. To be used in most reactors, ore must be first enriched and then fabricated into fuel rods. Unless they invest in costly and elaborate equipment to perform these steps, even nations with domestic uranium supplies cannot develop nuclear power as a means of meeting their own energy needs. While heavy-water reactors (e.g., the Canadian CANDU reactor) do not require enriched uranium, they can lead to energy independence only for countries with domestic uranium supplies, fuel fabrication ca-

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pacity, the ability to manufacture spare reactor parts, and facilities for producing heavy water.

Nuclear equipment represents vast amounts of embodied energy as well as materials. Energy use is concentrated primarily at the beginning of the nuclear power cycle when the facility is built and when the fuel is enriched. The old saw about the need to spend money to make money has a parallel here: to produce large amounts of energy, large amounts of energy must be invested in production. If the rate of growth projected by I.A.E.A. for nuclear power in the Third World holds, building and fueling nuclear reactors could consume more energy through the year 2000 then the reactors would produce, yielding a two-decade net energy drain. Moreover, virtually all the energy used would be consumed in the industrial world, which would receive none of the energy produced. As conventional energy sources grow more scarce and expensive, the industrial nations will no doubt think twice about encouraging the export of goods that have high energy costs.[22]

The inextricable link between commercial nuclear power and the spread of nuclear weapons poses still another obstacle to the use of the "peaceful atom." A standard 1,000-megawatt reactor operating at full power will produce about 375 pounds of plutonium each year. A crude atom bomb requires less than 20 pounds of plutonium. Weapons development may proceed whether or not nuclear power is commercialized, but commercialization certainly makes acquiring the equipment, fissile isotopes, and trained scientists needed for bomb building easier than it would otherwise be. The threat of terrorism would be compounded by the advent of commercial breeder reactors that produce more plutonium or other fissionable material than conventional reactors do.

The prestigious British Royal Commission report on nuclear power concluded that "the spread of nuclear power will inevitably facilitate the spread of the ability to make nuclear weapons" and that with respect to the construction of these weapons, there is "no reason to trust the stability of any nation of any political persuasion for

centuries ahead."[23] The growing understanding of this link between nuclear power and nuclear weapons has been reinforced by recent controversies over whether nuclear arsenals already exist in Israel and South Africa.

Mechanical breakdowns, construction faults, operator errors, or acts of sabotage could also create extraordinary dangers. That catastrophic events are possible is beyond doubt. How probable they are is subject to debate. Data are scarce and opinions vary widely. Virtually all detailed studies of nuclear dangers have covered only developed countries, and most have focused on the United States. Dangers unique to the Third World thus remain largely unexplored. Suffice it to remark that nuclear safety demands a degree of careful competence and, perhaps, sheer luck that are unusual in any culture.

One important limit on the applicability of nuclear technology to the Third World—or anywhere, for that matter—is imposed by the need for sensible overall system design. Interconnected electrical grids must be capable of continued operation even if their largest single power source fails. This is a particularly acute concern where nuclear reactors are employed since they have proven chronically unreliable. From 1968 through 1975, large U.S. reactors (800 megawatts and more) achieved average capacity factors of only 51 percent—versus the 70 to 80 percent predicted by the nuclear industry.[24] At least 6,000, and preferably 10,000, megawatts of installed capacity are needed to accommodate a single 600-megawatt reactor if power is to be maintained in all parts of the system whenever that reactor is shut down. By this criterion, only five Third World countries are in a position to accommodate securely even one small reactor.[25]

It is technically possible to build commercial reactors of very small size, and 150-megawatt or even 50-megawatt units are often discussed. But such small-scale reactors are not now on the market, and important economic factors (e.g., large and growing fixed costs that are not proportional to reactor size) make their development most unlikely. Moreover, since small reactors would find application only in poor countries, their development is of little interest to the countries that currently have nuclear manufacturing capabilities.[26]

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Experience in the United States holds particular relevance for developing countries that are considering making nuclear investments. Although endowed with enormous financial and technological resources, the U.S. nuclear program shows signs of coming apart at the seams. Nuclear opponents have repeatedly pointed out errors in reactor design, construction, and placement. The problem of radioactive waste disposal also remains unsolved. Taking these factors into account, President Carter has urged the world to halt the development of the Liquid Metal Fast Breeder Reactor and has also expressed opposition to the commercial reprocessing of plutonium. Westinghouse, a large American firm, recently unsettled the nuclear market by refusing to honor fuel-supply contracts with utilities because the world price of uranium had risen unexpectedly.

Reactor sales in the United States plummeted from 36 in 1973 to 27 the following year, to 4 in 1975, to just 2 in 1976. The uncertainties plaguing the development of nuclear power in the United States and, increasingly, in Europe and Japan suggest that countries thinking about importing nuclear technologies would be wise to hesitate until some of these uncertainties have been cleared up. Over and above the questions of high costs, plant safety, fuel availability, and waste disposal, developing countries must consider the likelihood that fears of weapons proliferation will lead the nuclear exporting countries to exercise strict controls in the future over the use of nuclear exports—controls that will necessarily intrude upon the sovereignty of states that buy nuclear facilities.[27]

The beleaguered nuclear industry continues to maintain that its problems are those that beset developers of any young technology and that the wrinkles will be gradually ironed out. Yet new difficulties have been emerging with noteworthy regularity, and the trend shows no sign of abating. The most recent problems are those related to decommissioning radioactive facilities—mills, enrichment plants, fuel fabrication facilities, reactors, and reprocessing plants—at the end of their usefulness. These costs will surely be large. The U.S. government is paying about $85 million to clean up residues from inoperative uranium mills. The cost of decommissioning a

"People ignore the sun for the same reasons that fish ignore water: it is abundant, free, and dependable."

commercial fuel-reprocessing plant in New York has been estimated to be as high as $600 million. Dismantling a single reactor could cost as much as $40 million. And estimates of the cost of decommissioning the Hanford facilities in the state of Washington (not including the disposal of 71 million gallons of highly radioactive waste) run to $4 billion.[28]

As the evidence mounts, commercial nuclear power looks more and more like a costly mistake. It is a mistake that the financially strapped Third World would do well to avoid.

Sustainable Sources of Energy

Every home is a solar home. People think they heat their homes with firewood, oil, or other fuels, but 95 percent of their warmth comes from sunlight. In a sunless world, each dwelling would be 240°C below zero before the furnace was turned on. The domiciles of "solar pioneers" simply use the sun's heat a little more efficiently than do the conventional homes of their neighbors.

If the sunlight that grows our food and fiber crops, the wind that blows swollen rain clouds to the mountains, and the firewood that provides half the world's population with most of its energy were measured by our energy accountants, conventional fuel use would appear insignificant. Every day the sun delivers to the earth thousands of times as much energy as we currently derive from all other sources.

The neglect of the sun by statisticians is not the result of an elaborate conspiracy of silence. People ignore the sun for the same reasons that fish ignore water: it is abundant, free, and dependable. With some minor fluctuations, the sun has bestowed its bounty on the earth for four billion years, and this generosity is expected to extend for several billion more. Even the sun's inconsistency is regional and seasonal, not arbitrary or political, and it can therefore be anticipated and planned for.

This solar influx can be harnessed directly as sunlight and indirectly as falling water and green plants. Every essential technological ingredient for a commercial solar system has existed for more than a decade, although many have not yet benefited from economies of mass production.

The issue today is whether we will adopt the necessary policies to develop these resources, or whether vested interests will coerce our continued reliance on sources that are dangerous, vulnerable to disruption, and ultimately unsustainable.

Solar energy sources produce no bomb-grade materials or radioactive wastes. They do not pollute, explode, or cause cancer. Dispersed near the points of end use, they are not easily disrupted by acts of God or man. Had industrial civilization been built upon such forms of energy "income" instead of on the energy stored in conventional fuels, any proposal to turn to coal or uranium for the world's future energy would doubtless be viewed with incredulity and horror. The current prospect, however, is the reverse—a shift from trouble-ridden sources to safe, sustainable ones.

Many decentralized solar technologies already exist for both urban and rural application. These can provide energy as heat, liquid or gaseous fuel, mechanical work, or electricity. The quality of energy sought from the sun and the costs of collecting, converting, and storing that energy usually correlate directly: the higher the desired quality, the higher the cost. Sources and uses must therefore be carefully matched, so that expensive, high-quality energy (e.g., electricity) is not wasted on jobs that do not require it.[29]

The simplest task to accomplish with sunlight is to provide heat. Sunshine can warm homes and workplaces, dry grain, or provide industrial process heat. Solar heating is often disparaged as a technology of little consequence, but the relevant data prove otherwise: most of the fuel burned around the world provides heat at temperatures that solar collectors could easily achieve.

Solar water heaters can be manufactured rather easily using materials that are either indigenous to the Third World or else recycled. Collectors made of old window panes, scrap metal, wood, and bamboo have worked effectively in some places. More sophisticated collectors can be mass produced fairly inexpensively. Japan, Israel, Australia, and the United States all have large and growing manufacturing capacities. About 20 percent of Israel's homes now employ solar water heaters. In Australia, the use of this technology is now required by law on new buildings in the Northern Territory. Japan today has about two million units installed, and annual sales equal several hundred thousand. Niger makes commercial solar water heaters, but because they are costly, the devices are used mainly to meet the needs of tourists.[30]

The United States has the world's most expensive solar water heating systems (with costs ranging from $10 to more than $30 per square foot of commercial collector) and comparatively inexpensive electricity. Yet recent U.S. studies have found solar water heaters to have an economic edge over electric water heaters.[31] If water temperatures no higher than 50°C (about 120°F) are required, much cheaper systems will suffice.

Washing dishes, utensils, and hands with hot water leads to a higher level of personal hygiene and a lower incidence of disease. Washing clothes with soap in warm water diminishes the amount of agitation needed to get them clean, thereby extending the garments' useful lives. While temperatures above the boiling point of water can be produced using focusing collectors, such collectors are difficult to manufacture from local materials. So where extremely hot water is needed, it may make more sense today first to preheat the water with a simple solar collector and then to use combustible fuel to provide the additional heat.

Sunshine can also be used to heat buildings. Although the Third World is thought by many to consist only of hot equatorial countries, buildings in the Andes, the Himalayas, Northern China, and most areas to the south of the Tropic of Capricorn have significant

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space-heating requirements. These can be met using any of several solar options. "Passive" solar heating systems store energy right where sunlight impinges on the building's walls and floors; such systems are designed to shield the structure from unwanted summer heat while capturing and retaining the sun's warmth during the colder winter months. Such designs, with windows facing the equator, carefully placed overhangs, and features that rely upon prevailing winds, are part of the architectural heritage of many developing countries. This heritage underscores the fact that it generally costs no more to build a home intelligently than to build it foolishly. Fuel savings of 50 percent and increased comfort are common where such designs are used. "Active" systems, in contrast, use solar collectors to capture sunlight and then transport it (using air or water as the medium) to a storage area, where it is later tapped as needed. Active systems are currently comparatively expensive, and most Third World residents will find it cheaper to fulfill their remaining heating needs (after employing passive solar designs) with firewood or other combustible fuels.

Solar cookers, most of which are parabolic mirrors that reflect and concentrate sunlight onto a grid or a pot, are simple and relatively cheap to build. Aimed toward the unobstructed sun, they cannot fail to work. Yet, for several reasons, they have never been successfully employed in the Third World. The use of solar cookers requires the adoption of new methods of meal preparation, and restricts cooking times to daylight hours. So it is not entirely surprising that in programs in Mexico and India, the cookers failed to win acceptance even when they were given away.

Slightly more sophisticated approaches that require fewer sacrifices or adjustments on the part of the users are now under development. Volunteers in Technical Assistance, a U.S. group interested in developing and promoting appropriate technology, is working on an uncomplicated acid storage-battery. When heated with a simple Fresnel lens, water evaporates from the acid to a separate compartment. At meal-preparation time, the device is turned upside down, the water is gradually recombined with the acid, and great amounts of heat are

"Sunlight can be used to cool things as well as to warm them."

given off. Other approaches receiving attention are slow reflective cookers, baking ovens, and stew pots.

Sunlight can be used to cool things as well as to warm them. Evaporative cooling for food storage and for personal comfort costs relatively little. It is particularly practical in hot, dry climates. More sophisticated technologies that produce lower temperatures are sold commercially in the United States and Japan. These solar absorption cooling systems are being employed in many new solar houses in industrial countries, and small versions could provide cost-effective refrigeration in developing lands, where keeping perishable foodstuffs and medicines is as difficult as it is important. Such systems have the advantage of working most effectively when the sun is brightest and cooling needs are greatest. (Large solar absorption air conditioners are now being planned for use in a hotel in Khartoum and at the U.S. embassy in Ouagadougou, Upper Volta.)

Poor water quality is a common problem in the Third World, and finding fresh water is perennially a major problem in the world's desert regions. The technology of solar stills is elementary: sunlight is used to evaporate water and then the condensate is collected. Such a still operated successfully in Chile from 1892 for about three decades. Although maintenance costs are low and fuel costs are zero, the initial capital investment is very high. The stills demonstrate no economies of scale, and show only limited promise for economies of mass production until new designs and materials are introduced. Distilled water from solar stills with 30-year lifetimes still costs about $4.50 per thousand gallons—three times the cost of water distilled at a large fossil-fueled facility. However, for small-scale applications, solar stills are already competitive. The University of the Philippines is conducting innovative research on low-cost stills, and several industrial countries are experimenting with more advanced designs.[32]

For thousands of years, people have been using the sun to dry grain, fruit, and timber. But traditional, open-air methods are slow, and the food sometimes decays before it dries. Simple solar collectors speed up the drying process and allow it to take place in confined structures where theft by rodents is minimized and rain is kept out.

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All of these heating and cooling technologies capture sunlight in the form of low-temperature heat, but other technologies can provide high temperatures. Concentrating collectors, which track the sun along one axis, can provide heat in the range of 100° to 300°C—temperatures sufficient to meet any need of the food, textile, chemical, and other industries. Such systems are now commercially available in the United States and are being applied in a soup-canning plant in California, a fabric-drying facility in Alabama, and a concrete-block factory in Pennsylvania. Such equipment could meet many of the energy needs of the various industries in the sunlight-rich Third World. A study commissioned by the Ford Foundation contends that solar collectors will first see widespread use in India in industrial applications.[33]

Solar collectors and solar ponds can provide a power source for various heat engines that can, in turn, convert this energy into useful work—such as pumping water or generating electricity. A 37-kilowatt (50-horsepower) irrigation pump was built and operated in Egypt in 1912. A French company is now marketing one-to-three-kilowatt solar water pumps for $15,000 per kilowatt. Battelle Memorial Institute recently built a 38-kilowatt solar pump prototype for about $7,000 per kilowatt and calculates it could be mass-produced for $2,000 per kilowatt. An American company now sells 10-kilowatt pumps for $4,000 per kilowatt, and expects the price to fall to $1,250 per kilowatt with mass production.[34]

Decentralized solar-thermal devices can be used to generate electricity, but conversion efficiencies are necessarily low. This technology appears to be most promising in applications where the unused heat collected can be productively employed, as it can for space heating or industrial purposes.[35]

The most exciting solar-electric device is the photovoltaic (or solar) cell—now the principal power source of orbiting space satellites that carry much of the world's international telecommunication traffic. Such cells generate electricity directly when struck by sunlight. They have no moving parts, consume no fuel, produce no pollution, op-

erate at ambient temperatures, last a long time, require little maintenance, and usually consist of silicon, the second most abundant element in the earth's crust.[36]

Solar cells are generally rated in terms of peak power—how much electrical wattage they produce in direct sunlight. The energy can be stored in batteries and used as needed. If the power is required evenly around the clock, about 5 *peak* watts of capacity will be required for every *average* watt desired. Fortunately, few activities use energy evenly around the clock; most energy demand is concentrated in daylight hours when the sun is directly available.

Solar cells are economical today only for remote applications, such as pipelines, drilling rigs, signal buoys, forestry stations, and Third World villages. They have been successfully employed to power educational television receivers in India and Niger, radio transmitters in the Andes, water pumps in Upper Volta, and refrigerators for storing medical supplies on an Indian reservation in Arizona.

Photovoltaic cells are modular by nature, and little is to be gained by grouping large masses of cells at a single collection site. On the contrary, the technology is most sensibly applied in a decentralized fashion—perhaps incorporated in the roofs of buildings—so that transmission and storage problems can be minimized. With decentralized use, the four-fifths or more of the sunlight hitting them that such cells currently cannot convert into electricity can be harnessed for space heating and cooling, water heating, and refrigeration.

The manufacture of photovoltaic cells is a low volume business, and the products are consequently rather expensive. But costs fell from an astronomical $500 per peak watt a few years ago to as low as $13.50 per peak watt in 1977, as volume grew to its current modest level.[37]

The U.S. Department of Energy expects price reductions to $1-2 per peak watt by 1980, 50¢ by 1986, and 10-30¢ by 1990.[38] At today's prices, solar cells can be economically applied to specialized Third World needs; at the expected 1980 price, they should see wide

application in developing countries; and at the 1990 price they could capture the lion's share of the international electrical generating market. As the prospect for solar cells has brightened, some of the "smart money" in American industry has seen the light.[39]

Solar energy can also be harvested indirectly in falling water, the wind, and plants grown as fuel. Water wheels have been used for millennia for such purposes as grinding grain, and locally built mills are still in use in some countries, including parts of Afghanistan and Turkey, where they are rather common. Water turbines spin much faster than water wheels and are used mostly to generate electricity. Units smaller than 100 kilowatts may account for one-third of all hydroelectricity in China. One report claims that the number of such facilities has grown from a total of 15,000 in 1968 to 35,000 by 1972 to more than 50,000 by 1974. The dams for virtually all these plants have been locally built, usually of earthfill.[40]

The potential of small-scale hydropower technologies has never been thoroughly studied. Most research has focused strictly on identifying optimal sites for huge dams and storage reservoirs. But now that these large facilities are running up against major problems—the flooding of good agricultural lands, the displacement of vast numbers of people, and the spread of schistosomiasis—new attention is being paid to alternatives of less elephantine dimensions. A recent report by the U.S. Army Corps of Engineers found that in the United States 54,000 megawatts of generating capacity could be installed at more than 50,000 *existing* dams 25 feet or higher (built for agricultural purposes or flood control rather than for power).[41] Installed U.S. nuclear generating capacity, by comparison, is only 48,000 megawatts.

Especially in the mountainous tributary regions of the Third World, small-scale hydropower technologies appear to hold great promise. The units, available from China, West Germany, Britain, or the United States, are relatively inexpensive, and local labor can build the needed dams and divert selected streams.

"Smaller windmills produce power in much slower winds, and thus can operate a higher percentage of the time."

Machines to tap the energy in the wind, like those that harness water power, are of two basic types: mills and turbines. Windmills turn slowly and are used for high-torque work like pumping water. Wind-turbines turn much more rapidly and are ordinarily used to generate electricity. Wind power production increases with the square of a propeller's size, so large wind machines produce far more energy than do small ones. Moreover, wind power increases with the cube of velocity; thus a 10-meter-per-second wind produces eight times as much power as a 5-meter-per-second breeze does. Some wind power enthusiasts therefore think exclusively in terms of huge turbines on very windy sites. A recent survey of large U.S. corporations conducting wind power research disclosed that only one of them had any interest in small or intermediate sized turbines.[42] But the "think big" approach is not necessarily appropriate for either the agrarian or the industrial world. The crucial question is how much energy is harnessed per dollar of investment. Increases in output are desirable only if the value of the additional energy extracted exceeds the extra cost, and economic optimization need not mean giant turbines. Smaller windmills would lend themselves more easily than large ones to mass production or to local construction from available materials. They also produce power in much slower winds, and thus can operate a higher percentage of the time.

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Wind machines have had a distinctly mixed history in the Third World. Because of poor maintenance and shortages of parts, windmills have been abandoned in Mali and Uganda. In Tanzania, the selection of windmills unsuited for local wind conditions led to chronic problems, and most of those in isolated regions appear to have broken down. On the other hand, another Tanzanian program appears to have worked quite well, and success stories have also been reported out of Zambia and Argentina. Of particular interest is the occasional smooth transfer of a successful low technology from one region to another. For example, the Geleb people in the Omo River region of Ethiopia have begun building a sail-wing windmill to pump water, adopting a design that has been in use for hundreds of years on Crete. The Ethiopian wind-pumpers are constructed of local materials and appear to be performing admirably.[43]

30 Small-scale wind turbines to produce electricity cost as little as $500 per kilowatt for 15-kilowatt generators. When coupled with hydropower as a back-up, intermediate-sized wind machines are today an economical source of electricity, even in the industrial world. Future economies—perhaps of scale and certainly of mass production—should lower costs.

A final option is to harness sunlight indirectly by tapping the solar energy stored in the chemical bonds of green plants. One such energy source is firewood, which already contributes about 15 percent as much commercial energy each year as do the fossil fuels. Ambitious "plant power" plans abound. Brazil, for example, hopes to grow sugar cane and cassava for their energy content and to convert them into ethanol. By the year 2000, it hopes to substitute the resulting alcohol for all its imported gasoline. The Philippines plans to use coconut husks as fuel for electrical power plants. The annual crop could displace two million tons of imported diesel fuel.

Biogas technologies employ anaerobic bacteria to digest animal dung, human excreta, and other organic wastes to produce methane, the chemical equivalent of natural gas. The residue of the process is a high quality fertilizer, free of many of the pathogens and weed seeds originally among its ingredients.[44]

Development of biogas technology has been carried farthest in China, despite the fact that China's climate is far from ideal for this technology. The first attempt to promote the technology in 1958 failed, but in 1970-72, a few hundred biogas plants were built in Szechwan. So successful were they that a national program was begun in earnest. By mid-1975, 100,000 biogas technicians had been trained. In May 1977, the New China News Agency reported 4.3 million working units—many of them communal plants producing up to 100 cubic meters of gas per day, each able to meet the needs of 50 Chinese peasants. Recent reports indicate that 17 million people use biogas for cooking and lighting in Szechwan province alone. The capital cost of a ten-cubic-meter tank to serve a 5-person family is between $15 and $20, depending upon the materials used. Costs have fallen by more than

half in the last five years. In Hunan province, such a biogas plant is expected to save a typical family 40 person-days and about $15 per year.[45]

Biogas technologies are well understood, and they are reliable within certain temperature ranges if appropriate mixtures of ingredients are fed into the system and toxic contaminants are kept out. But social obstacles, including an unwillingness in some cultures to handle dung, impede their use. The dung from at least three head of cattle (or equivalent organic matter from another source) is needed for the smallest economical digester, and the technology makes most sense where cattle are kept in enclosed areas. Poor people cannot make profitable use of an individual digester, and even in village collectives, agreements regarding the collection of dung, the use of equipment, and the distribution of the resulting fuel and fertilizer must be hammered out.

Direct sunlight, wind, water, and biological sources all hold great promise as Third World energy sources. All that is needed today is the political and economic commitment to build a sustainable energy system.

Energy Priorities for the Third World

The Third World faces difficult energy choices. With little capital, few trained technicians, scanty infrastructure, inadequate reserves of conventional fuels, and a large and rapidly growing population, it has little margin for error. Any commitment of resources to one energy option will necessarily deny them to another.

Energy is the means to an end; it is not valued in itself, but only for the work it can perform. To construct an intelligent energy policy for any society, planners must first ask what work needs to be done, and then determine how much energy in what form will be required to perform it. These requirements then can be matched against the energy sources available, and reasonable choices can be made.

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The basic human needs are for food, clean water, shelter, and health. Once these have been satisfied, societies can choose from a variety of other possible energy uses on which to spend remaining energy supplies. Since societies have different human and physical resources, some will pursue different goals than others. Some will emphasize agriculture, others industry, still others services (such as banking or tourism).

Satisfying basic needs requires very little energy. Moreover, these needs can be easily met in the Third World if it uses judiciously the sustainable energy sources with which it is abundantly endowed. Most of these resources are rather diffuse and are comparatively difficult to harness to provide the energy needs of large cities. But, fortuitously, the overwhelming majority of the populations of most Third World countries inhabit small villages in rural areas.

Yet, most Third World capital expenditures for energy are now being sunk into centralized facilities designed to serve large urban conglomerations. Both these biases toward assigning top priority to the needs of urban areas should be reversed, although the task will be difficult. "Those in power always want big accomplishments—scientific accomplishments and politically visible facilities," explains M.C. Gupta, Director of the Thermodynamic Laboratory at the Indian Institute of Technology. Cities are more "visible" than villages and urbanites also tend to be better educated and better organized politically than the inhabitants of the surrounding countryside. (On the other hand, successful modern revolutions—as opposed to riots or coups d'etat—have more frequently been carried out by a disenchanted peasantry than by a rebellious urban proletariat.) If the greatest good for the greatest number is to be the aim, highest priority among investments in new energy sources should be given to decentralized facilities designed to provide on-site power to remote rural villages where most people live.[46]

In the past, most capital dedicated to energy has been spent on conventional energy sources, even in countries that were 90 percent dependent upon renewable sources. Resources desperately needed for

reforestation projects and small-scale hydroelectric facilities and village wind turbines have been squandered on technologies poorly matched to the real needs of most people in the Third World. Officials have not wanted to settle for "second-rate" renewable energy sources while the industrial world flourished on oil and nuclear power.

Many attitudinal impediments to the use of solar technologies may now be vanishing as the global south begins developing its own research and development capacity, and as the risks of dependence on oil and nuclear power become clear. The resulting indigenous technologies may prove to be more compatible than borrowed machines and methods with Third World needs and goals. Brazil's large ethanol program, India's gobar gas plants, and Saudi Arabia's growing fascination with solar electric technologies can be all read as signs of an interest in renewable energy resources that bodes well for the future. In addition, the simultaneous shortages of firewood and petroleum further encourage Third World interest in solar solutions. Finally, many Third World leaders may be recognizing that it would be foolhardy to base their energy-development plans upon an energy source with no future.

It is as important for the Third World as it is for the industrial world to view energy conservation as a legitimate object of massive public support. Because energy must be invested in order to deliver energy in a useful form—firewood requires long walks with heavy bundles; coal must be mined and transported—a unit of energy saved in end use will additionally save the energy otherwise lost in the production process. In the case of firewood, conservation reduces a burden that in most cultures falls disproportionately upon women and children who do the gathering. Investments in conservation, such as pressure cookers and more efficient stoves, will almost invariably save more energy than similar investments to increase supplies would produce.[47]

Solar energy and energy conservation present the Third World with new opportunities, but technological innovations provide benefits only to those who can afford them. The agricultural Green Revolution, for example, vastly increased food production in many areas of

the world, but the incremental wealth often served solely to make the rich richer.

So too, the introduction of renewable energy technologies can bring disproportionate benefits to the rich. In fact, it can easily leave the poor worse off, in both relative and absolute terms. Consider, for example, biogas plants—a perfect textbook case of an appropriately-scaled renewable energy technology. "Gobar" gas plants, experimented with in India since the 1940s, use anaerobic bacteria to convert cow dung into combustible gas and rich fertilizer. The gas is a more useful fuel than is dried dung when burned directly, and the fertilizer produced is more valuable than dung would be if it were returned directly to the fields. But, especially in the early years, this technology was adopted and used to advantage only by relatively rich farmers. (Even today, individual plants are limited to families who own at least three cows.) Meanwhile, dung, which was formerly worthless to the rich, acquired a value, and the poor were no longer able to find it along the roadside. A partial answer has been for the government to provide higher subsidies to the poor than to the rich, thus allowing a larger fraction of the rural populace to take advantage of the technology. The highest subsidies are reserved for communities that elect to build cooperative plants (although the truly destitute are often excluded even from these). But where measures to ensure a reasonably equitable distribution of the benefits from the technology are not taken when it is introduced, this exceptionally attractive and relatively inexpensive energy source can work to the genuine disadvantage of much of the rural population.[48]

Sales of the French solar pump marketed by SOFRETES have had similar consequences. Sales are now being subsidized in order to build a large market, and mass production is expected to lower the pump's cost from the present $40,000 to less than $8,000. But even $8,000 is an almost inconceivable sum of money to most of the world's rural poor. Indeed, most large villages would have trouble raising this amount. In the Mauritanian village where the first such commercial pump was installed, water used to be free, and children were responsible for carrying it to their homes from the well. But the two richest

"New energy sources do not constitute a simple technical fix to the world's most difficult social and economic problem: the uneven distribution of wealth."

inhabitants of the village have now taken control of the pipeline, and they are selling their neighbors water and denying children the chance to contribute to the well-being of the community.[49]

Objections and reservations can, of course, be raised against any new source of energy, whether a nuclear reactor or a simple solar water heater. Capital must be invested to reap the advantages any technology can bestow, and people who earn less than 50¢ a day will have trouble saving any money for investment. But to recognize the obstacles is not to argue against the development of new energy sources. It is, rather, to acknowledge that new energy sources do not constitute a simple technical fix to the world's most difficult social and economic problem: the uneven distribution of wealth. Consequently, if profound social change does not accompany the introduction of biogas plants, windmills, or photovoltaics, only the rich will have energy. The wedge driven into the income gap as a result may lead to a more painful readjustment later.

However, it must be recognized that solar energy resources are inherently more egalitarian than their alternatives. They are abundant throughout the Third World and require no expensive transmission grid or pipeline system to distribute. They are, by nature, anti-monopolistic. Moreover, the greatest division between rich and poor is that which separates urban dwellers from rural inhabitants; and renewable resources are, in general, most easily tapped to meet rural needs.

Perhaps the most difficult problem is that of distributing capital to those who most need it. Central governments can much more easily spend their revenues on a handful of gigantic projects than on millions of smaller ones—whatever the relative payoffs of the two strategies. This problem, however, is not intractable, as the success of decentralized technologies in China demonstrates.

If means can be found to give everyone access to solar technologies and energy-saving equipment, a constructive process of self-multiplication will begin. Once installed, such technologies will begin to save

the purchaser money. These savings, in turn, can be invested in still more equipment, thus multiplying the savings. The end result could provide a meaningful contribution to the solar transition.

Since investment funds tend to become available where energy is available, a transition to gentle, sustainable energy sources could bring with it vast developmental benefits for the Third World. Whereas complex nuclear and coal-based technologies would divert a major stream of scarce capital to the industrial world, the development of safe and sustainable indigenous sources could cause investment dollars to flow in the other direction. Many primary industries now compete vigorously for the right to build plants in the Middle East, less to penetrate the region's small markets than to be assured of a supply of fuel. As renewable sources attract more adherents, hard currencies can be expected to flow to the world's richest sources of sunlight, wind, water, and biomass, and many of these are located in the Third World.

The end of the oil age is within view, and the Third World, amply endowed with the energy sources that are likely to dominate the next major energy era, need not fear that end. The critically important problem is to begin the solar transition early enough and pursue it vigorously enough to have a viable system in place by the time it is needed. No higher use could be made of the world's remaining petroleum than to mine, refine, and fabricate the materials the world will need to build a sustainable energy system.

1. While dreadfully low, energy use in the world's poorer countries is higher than official statistics suggest. Data are usually compiled only for fuels commonly used in the industrial world, and in many Third World countries such conventional sources count for only a small fraction of total energy use. According to the standard U.N. reference volume, *World Energy Supplies: 1950-1974*, the typical American uses 164 times as much energy as the average Tanzanian and 957 times as much as the average Nepalese. However, according to D.F. Earl, *Forest Energy and Economic Development* (Oxford: Clarendon Press, 1975), firewood accounts for an estimated 96 percent of all the fuel used in both Tanzania and Nepal, and firewood is not even mentioned in the U.N. tables. When *all* energy is counted, the average American uses about 40 times as much energy as the average Nepalese. 37

For sub-national geographical areas, the comparisons are more dramatic. In northern Nigeria, non-commercial energy is thought to outweigh conventional forms of energy by nearly 160 to one. In parts of rural Bolivia, unconventional sources provide the energy equivalent of 1,236 kilograms of coal per capita each year. But because they consume no oil, gas, or coal, these Bolivians are assumed for statistical purposes to use no energy at all. See Roger Revelle, "Requirements for Energy in the Rural Areas of Developing Countries," in Norman L. Brown, ed., *Renewable Energy Resources and Rural Applications in the Developing World* (Washington, D.C.: American Association for the Advancement of Science, 1976). The most current, comprehensive, and balanced assessment of Third World energy prospects I have read is an October 31, 1977, draft report to the Rockefeller Foundation by James Howe, James Beaver, William Knowland, and James Tarrant of the Overseas Development Council. Entitled *Energy for Developing Countries*, the 330-page manuscript is scheduled for publication in 1978.

2. In several independent studies of global energy prospects, similar conclusions about oil depletion rates are drawn. See, particularly, the comprehensive report of the Workshop on Alternative Energy Strategies, *Energy: Global Prospects 1985-2000* (New York: McGraw-Hill, 1977).

3. The energy/GNP ratio of a country varies with climate, economic structure, choice of technology, lifestyle, and other variables. The confusion is compounded in the Third World, where much of the national product is bartered (and hence not counted in GNP) and where official exchange rates often do not reflect true values. See Irving B. Kravis *et al., A System of International Comparisons of Gross National Product and Purchasing Power* (Baltimore: John Hopkins Press for the World Bank, 1975). Statistical conversions of conventional and traditional energy sources are particularly confusing. In much of East Africa, for example, people who cooked with kerosene five years ago have now reverted to using charcoal. This switch has caused some inconvenience, but not serious hardship. But because charcoal consumption is not recorded in official statistics, energy use appears to have declined dramatically.

4. Barbara Ward, *The Home of Man* (New York:W. W. Norton, 1976).

5. Just six countries—India, Brazil, Mexico, Argentina, South Korea, and Taiwan—use half of all electricity consumed by 110 developing nations. The World Bank estimates that, as of 1971, rural electrification programs had reached about 12 percent of the people in the rural Third World: 23 percent in Latin America, 15 percent in Asia, 15 percent in the Middle East and North Africa, and 4 percent in sub-Saharan Africa. (Only half of those "within reach" can afford to buy power.) If service spreads as expected at about 1 percent per year, three-fourths of the rural residents of the Third World will still be without electricity at the century's end. See *Rural Electrification* (Washington, D.C.: World Bank, October 1975). Nonetheless, investments in electric-power capacity typically constitute 60-80 percent of all national energy investments in developing countries, even those in which the vast majority of people have no electrical outlets. See Vladimir Baum, "Energy in Developing Countries: Prospects and Problems," presented to the International Conference on Nuclear Power and Its Fuel Cycle, Salzburg, Austria, May 2-13, 1977.

6. James Howe and Norman Brown, "Solar Energy for African Village Development," *Science*, in press: for photovoltaic cost forecast, see *E.R.D.A. Announcements*, September 30, 1977.

7. Charles Weiss and Simon Pak, "Developing Country Applications of Photovoltaic Cells," paper presented to E.R.D.A., January 20, 1976; Douglas V. Smith, "Photovoltaic Power in Less Developed Countries," Lincoln Laboratory, Massachusetts Institute of Technology, Cambridge, Mass., March 24, 1977.

8. For example, the International Development Association charges 0.75 percent interest on loans, with 10 years' grace and 40 years to repay.

9. Arjun Makhijani with Alan Poole, *Energy and Agriculture in the Third World* (Cambridge, Mass.: Ballinger Publishing Company, 1975). The authors also argue that adopting such a policy would mitigate pressure on farmers to have large families. Although in everyone's best interest, job creation is not guaranteed. Villagers unable to buy or rent land have no income or political leverage except at times of peak demand. If machinery is used to shave the peak labor demand and alternative employment is not provided, the poorest will either move to the city or starve or both. Clearly, new employment opportunities must be made available *at the time* that the labor-saving technologies are introduced.

10. F. de Winter and J.W. de Winter, eds., *Description of the Solar Energy R&D Programs in Many Nations* (Santa Clara, California: Atlas Corporation, February 1976).

11. Denis Goulet, *The Uncertain Promise: Value Conflicts in Technology Transfer* (New York: IDOC/North America, in cooperation with the Overseas Development Council, 1977); E.F. Schumacher, *Small is Beautiful: Economics as if People Mattered* (London: Blond and Briggs, Ltd., 1973).

12. Charcoal and firewood shortages are examined by Erik Eckholm in *The Other Energy Crisis: Firewood* (Washington, D.C.: Worldwatch Institute, September 1975). Some particularly acute forage problems are discussed by Eckholm and Lester R. Brown in *Spreading Deserts—The Hand of Man* (Washington, D.C.: Worldwatch Institute, August 1977). (I have never seen a comprehensive survey of future forage availability, yet forage is the "fuel" that drives Third World agriculture. According to the *Asian Agricultural Survey: 1976* (Manila: Asian Development Bank, April 1977), in 1972 in India, 130,000 tractors provided less than three million horsepower while 85 million draft animals provided an estimated 34 million horsepower.) These issues are put into useful perspective in Lester R. Brown, *The Twenty-Ninth Day* (New York: W. W. Norton, 1978).

13. Food and Agriculture Organization, *World Forest Inventory, 1963* (Rome: 1965).

14. Keith Openshaw, "Wood Fuels the Developing World," *New Scientist*, January 31, 1974. See also Alan Poole, "Bioenergy in Underdeveloped Countries," privately circulated paper from Institute for Energy Analysis, Washington, D.C., 1977. In a study of fuelwood consumption in a Tanzanian village, Patrick and Anne Fleuret found that each villager would have to plant about seven trees a year to keep pace with current usage. "Fuelwood Usage in a Peasant Village," submitted to *Journal of Developing Areas*, 1977.

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37. Only 750 kilowatts of photovoltaic capacity were produced in 1977. Cumulative world production to 1977 was about 2,000 kilowatts.

38. Details of how these savings are to be achieved are given in *E.R.D.A. Announcements,* September 30, 1977. Allen Hammond, in "Photovoltaics: The Semiconductor Revolution Comes to Solar," *Science,* July 29, 1977, discusses some of the more advanced photovoltaic concepts now in the experimental stages.

39. U.S. firms with an active involvement in photovoltaics include IBM, Texas Instruments, Varian, RCA, Motorola, Shell Oil, Mobil Tyco, Dow Corning, and Union Carbide, as well as Solarex and several small semiconductor firms. Important work is also being done by French (especially Photon Power) and Japanese firms.

40. James E. Nickum, "Hydraulic Engineering and Water Resources in the People's Republic of China, 1974," cited in Howe *et al., Energy for Developing Countries.* See also Vaclav Smil, "Intermediate Energy Technology in China," *Bulletin of the Atomic Scientists,* February 1977. Some institutional aspects of the Chinese program are discussed in American Rural Small-Scale Industry Delegation, *Rural Small-Scale Industry in the People's Republic of China* (Berkeley: University of California Press, 1977).

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42. Stewart W. Herman and James S. Cannon, *Energy Futures* (New York: Inform, Inc., 1976).

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44. A.K.N. Reddy of the Indian Institute of Science in Bangalore has written a widely circulated article, "Power to the Poor," contrasting biogas plants with coal-fueled fertilizer facilities. In India today there is a crying need for nitrogen fertilizer. A large, coal-fueled fertilizer factory will produce 230,000 tons per year; so would 26,000 biogas plants. But the biogas plants would cost $15 million less to build, and all the money invested would be spent inside India, saving $70 million in foreign exchange. The biogas plants would provide 130 times as many jobs and these jobs would be located in rural villages, where most people live and where employment is most desperately needed. Biogas plants would also produce the fertilizer where it is needed, eliminating the transportation requirements. Finally, the coal-fired plant *consumes* enough fuel every year to meet the energy needs of 550 Indian villages, while the biogas plants would *produce* enough fuel each year to meet most of the energy needs of 26,000 Indian villages.

45. Vaclav Smil, "Energy Solution in China," *Environment*, October 1977.

46. The best treatment I have seen of the urban-rural division is in Michael Lipton, *Why the Poor Stay Poor: Urban Bias in World Development* (Cambridge, Mass.: Harvard University Press, 1977).

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48. Other examples of the ways appropriate technologies can work against the interests of the people they are intended to serve can be found in Joseph Hanlon, "Does A.T. Walk on Plastic Sandals?," *New Scientist*, May 26, 1977.

49. Nicolas Jequier, *Appropriate Technology: Problems and Promises* (Paris: Organization for Economic Cooperation and Development, 1976).

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